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Impact of eutecto-oleogel on functional, textural and rheological attributes of wheat flour cookies as a fat replacer

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The study aimed to understand the effect of eutecto-oleogel on wheat dough and cookie quality. The oleogel was prepared using rice bran oil, beeswax, starch, and natural deep eutectic solvents (NADES), constituting malic acid and glucose. The quality of the cookies was evaluated based on their physicochemical, functional, rheological, and textural properties at oleogel concentrations ranging from 20% to 100% of total fat. The qualitative properties of the cookies, such as dimensions, color, water solubility, and textural properties, varied significantly ($p > 0.05$). The basic chemical composition, textural properties, and physical attributes of the cookies were compared with control sample and sample with NADES provided a better acceptability. Sensory analysis using a 9-point hedonic scale was conducted and the sample with 60% oleogel showed the highest overall acceptability. Furthermore, changes in the cookie texture and stability were monitored over 35 days of storage at room temperature (25 °C) under 75% and 94% RH. It was found that in almost all the properties, the oleogel cookies resembled the control cookies. This manifested a new approach to replace solid fats in confectionery.

Sustainability spotlight

The incorporation of eutecto-oleogels as fat replacers in wheat dough and cookies offers a sustainable alternative to conventional solid fats. Forming oleogels from healthier unsaturated oils reduces dependency on saturated fats and the associated health risks. Eutecto-oleogels serve dual purposes of improving textural homogeneity and moisture retention in food products while maintaining dough-handling qualities. This innovation not only supports health-driven reformulation but also promotes the use of plant-based lipids, contributing to more sustainable and nutritionally responsible bakery products.

1. Introduction

Solid or semi-solid fats are widely used in the bakery industry because of their significant impact on the flavour, texture, and oxidative stability of food products.[1] Consequently, techniques like interesterification and hydrogenation are employed to convert liquid oils into solid or semi-solid fats.[2,3] Saturated and trans fatty acid concentrations in the oil increase after hydrogenation and their detrimental effects on human health have been extensively demonstrated.[4] According to the U.S. FDA, consumption of saturated fat results in increased blood levels of total cholesterol and low-density lipoprotein (LDL or "bad") cholesterol, which in turn increases the risk of cardiovascular disease. Cardiovascular disease is the leading cause of death in both men and women in India, and a similar trend is observed all over the world. As per WHO recommendations, the daily consumption of saturated fatty acids must not exceed 10%. The United States officially banned the use of trans fat by removing partially hydrogenated oils from the GRAS (Generally Recognized As Safe) list in June 2018, making their addition to foods illegal. Canada's nationwide ban on the use of trans fats came into effect in September 2018. The State of California banned its use in 2010, and it was banned in New York in 2008. An alternative method needs to be developed to transform liquid vegetable oils into solid or semi-solid fats with low contents of trans and saturated fatty acids.

Oleogelation is an innovative alternative technology that has attracted significant attention in recent years.[5] The process of trapping oil in a 3D network using a low concentration of oleogelator chemicals without changing the fatty acid composition of the oil, unlike hydrogenation, is known as oleogelation (also known as organogelation).[6] Numerous biopolymers, including proteins, polysaccharides, and their combinations, are employed for the hydrogel phase. Thus, oleogels are structured solid-like materials in which a high amount of liquid oil is entrapped within a self-standing, anhydrous, thermoreversible, three-dimensional network of gellator molecules.[7] The potential uses of this technique have attracted significant attention for

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applications in various bakery products.[8,9] However, the application of eutecto oleogels in bakery products has been limited.

Cookies are highly consumed ready-to-eat and convenient baked flour confectionery, with a global market estimated at USD 12.14 billion in 2024 and expected to grow to USD 18.77 billion by 2029. Solid fats in cookies serve the primary function of lubricating gluten particles to prevent large chain formation, improve dough plasticity and tenderize the finished product. Growing awareness and health concerns have led consumers to seek better alternatives in food consumption, driving the market expansion of healthy cookies.[10] Various studies have been conducted to discover the potential of oleogels to replace the solid fat in cookies. Previous research revealed the effect of oleogels made with Hazelnut oil, sunflower oil, virgin olive oil, flaxseed oil, and soybean oil structured using different types of waxes (*e.g.*, carnauba wax, rice bran wax, sunflower wax, beeswax, candelilla wax) on cookie manufacturing.[11,12] However, eutecto oleogels with rice bran oil were not used in cookies.

Therefore, the current study aimed to develop cookies with an eutecto-oleogel. It was assumed that the eutecto-oleogel would be an alternative to fats and would not vary the properties of cookies as compared to conventional fats. Thus, the objectives of the study were a) development of cookies with an eutecto-oleogel, b) the physiochemical and flow properties of the dough and comparison with conventional cookies and c) effect of oleogel on the sensory properties and shelf-life of the cookies.

2. Materials and methods

2.1. Raw materials and chemicals

Rice bran oil was purchased from Tezpur, Assam, India. Malic acid and glucose were procured from SRL (Maharashtra, India). Beeswax of *Apis mellifera* was purchased from HiMedia Laboratories Pvt. Ltd (India). It is a lipid that contains hydrocarbons, esters and free acids. Joymoti rice starch was collected from the Food Engineering and Technology Department, Tezpur University. Refined wheat flour, sugar, baking powder, salt and butter were procured from a local market in Tezpur. All other reagents and chemicals used for analysis were of analytical grade.

2.2. Preparation of oleogel

The oleogel was prepared using rice bran oil, beeswax, starch and natural deep eutectic solvents (NADES) containing malic acid and glucose in the ratio 1 : 1.[13] For oleogel preparation, NADES and starch were first mixed to obtain a uniform mixture using a magnetic stirrer. Subsequently, rice bran oil was added to the mixture while being mixed and heated simultaneously to 80 °C for 30 min using a temperature-controlled magnetic stirrer. Once the mixture reached the desired temperature, the beeswax was incorporated while mixing continuously. To facilitate gel formation, this homogeneous mixture was cooled to room temperature, followed by resting for 24 h at 20 °C. The sample containing 9% beeswax, 1% starch and 15% NADES in reference to 100% rice bran oil (RBO) was selected for this study based on observations from our previous research work.

2.3. Preparation of cookies

Six different cookie samples were prepared with varying proportions of oleogel and butter, as listed in Table 1. Six different samples, with varying ratios of butter and oleogel (100 : 0, 80 : 20, 60 : 40, 40 : 60, 20 : 80,0 : 100), were prepared, keeping the overall shortening at 30 g. The samples were prepared according to the method given by Hamdani, Wani, and Bhat.[14] For preparing the dough, 100 g of refined wheat flour was thoroughly mixed with 30 g shortening for 3 min. Then, 0.5 g of baking powder was added and mixed thoroughly. Finely powdered white sugar weighing 45 g was added to the mixture and further mixed for 1 min. After that, 0.5 g of salt dissolved in 2 ml of water to ensure proper mixing was introduced into the sample and mixed thoroughly for 1 min. After thoroughly mixing all ingredients, 15 ml of water was added, and the dough was prepared by kneading it for 3 min. The prepared dough was allowed to rest for 5 min. Then, the dough was rolled to a thickness of 5 ± 0.5 mm using a flat board and rolling pin and then cut into circular shapes using a die with a 50 mm diameter. Fifteen cookies were placed on an aluminum tray in one go and baked at 180 °C in the baking oven. The baked cookies were cooled to room temperature (25 ± 1 °C) and were stored in an airtight container at room temperature until further analysis.

2.4. Weight loss and dimensions of cookies

The weight loss in cookies during baking was measured for a sample of 15 randomly selected cookies. For this, the difference between the final weight of baked and cooled cookies and the initial weight of each cookie sample was measured. The diameter and thickness of the 15 selected cookies were

Table 1 Composition of the cookies and coding

	Composition (g)						
Samples	Flour	Butter	Oleogel	Sugar	Baking powder	Salt	Water (ml)
O_0	100	30	0	45	0.5	0.5	17
O_{20}	100	24	6	45	0.5	0.5	17
O_{40}	100	18	12	45	0.5	0.5	17
O_{60}	100	12	18	45	0.5	0.5	17
O_{80}	100	6	24	45	0.5	0.5	17
O_{100}	100	0	30	45	0.5	0.5	17

measured according to Emin Yılmaz and Mustafa Öğütcü[11] using digital vernier calipers. The spread ratio was calculated as described earlier[15] and expressed as the ratio of the average diameter to the average thickness of the cookies.

2.5. Color analysis

The color of 15 selected cookies from each sample type was quantified through CIELAB parameters (L, a, and b) by using Hunter Lab Ultra Scan VIS Spectrophotometer (Hunter Lab Inc., Reston, VA, USA). Data were analyzed using Easy-Match QC software.

2.6. Textural properties of cookies

The hardness and fracturability of the 15 selected cookies were analyzed using a texture analyser (Model # TAHD Plus; Make # Stable Microsystems, UK) equipped with a 30 kg load cell and Warner-Bratzler rectangular notch blade probe. The analysis was performed with a pre-test speed of 3 mm s^{-1}, test speed of 1 mm s^{-1}, post-test speed of 5 mm s^{-1} and triggering force of 0.100 N. The resultant force–time curves were evaluated for the maximum peak force, which indicates hardness, and the first significant peak force, which indicates the fracturability of the cookie sample.

2.7. Functional properties of cookies

The functional properties of the prepared cookie samples, such as Water Absorption Index (WAI) and Water Solubility Index (WSI), were analyzed according to Hashem *et al.*[16] The cookie samples were finely ground and for the water absorption index, 4 ± 0.5 g of the powdered cookie sample was transferred to a weighed centrifuge tube, followed by the addition of 30 ml of distilled water. The slurry was stirred with a glass rod to break any possible lumps present and further centrifuged at 3000 rpm for 10 min at ambient temperature (25 °C) in a centrifuge (Model # 5430R; Make # Eppendorf Germany). The supernatant and sediment were separated appropriately; the weight of the sediment gel was recorded, and the water absorption index was calculated using eqn (1).

$$\text{WAI}(\%) = \frac{\text{weight of sediment}}{\text{weight of dry sample}} \times 100 \quad (1)$$

For determining the water solubility index, 2.5 g of finely ground cookie sample was added to 25 ml of distilled water and stirred for 30 min using a magnetic stirrer. The slurry was transferred into a tarred centrifuge tube, made up to 32.5 g and further centrifuged at 3000 rpm for 10 min at ambient temperature (25 °C) using a centrifuge (Model # 5430R; Make # Eppendorf Germany). The supernatant was carefully transferred to a previously weighed evaporating aluminum dish, and the dissolved solids in the supernatant were recovered by evaporating the liquid. The water solubility index was calculated using eqn (2)

$$\text{WSI}(\%) = \frac{\text{weight of solid recovered from supernatant}}{\text{weight of dry sample}} \times 100 \quad (2)$$

2.8. Rheology of dough

Rheological analysis of dough was carried out according to Das *et al.*[17] with slight modification. Frequency sweep analysis was performed by a rheometer (Physical MCR 72, Antron Paar, Graz, Austria) using 25 mm flat probes to determine the strength of the dough. Analysis was performed at ambient temperature by applying a constant strain of 1% and varying frequency from 1 to 100 rad per s. The storage and loss modules of samples were determined.

2.9. Compositional analysis

The moisture content of the cookie samples was analyzed according to AOAC method 925.10 using a hot-air oven. The ash content of the cookies was determined using the AOCS Ba 5a-49 technique. Soxhlet apparatus was used to measure the total fat content of the cookies using the AOAC 920.39 method. Crude protein content was measured using the Kjeldahl method as per AOAC, 2005, method 979.09.[18] All the readings were taken in triplicate.

2.10. Sensory analysis

The sensory evaluation of the cookie samples was performed according to Owheruo *et al.*[19] with slight modification. Semi-trained panelists of 15 members belonging to the age group of 18 to 35 years and with different eating habits voluntarily participated in the sensory evaluation. The panelists were staff and students of the Department of Food Engineering and Technology, Tezpur University. The samples were evaluated for color, texture, taste, flavour and overall acceptability based on the 9 points hedonic scale (1-dislike extremely; 2-dislike very much; 3-dislike moderately; 4-dislike slightly; 5-neither dislike nor like; 6-like slightly; 7-like moderately; 8-like very much; 9-extremely like).

2.11. Storage study

The cookie samples were standardized based on sensory analysis. The standardized (O_{60}) and control (O_0) samples were prepared and stored in zippered polypropylene bags at two different relative humidity levels (75% and 94%) attained using sodium chloride and potassium nitrate salt at 25 °C. Every 7th day, the samples were withdrawn and analyzed for weight gain, moisture content, texture and peroxide value. The peroxide value was measured according to the method given by AOAC.[18]

2.12. Statistical analysis

To identify significant differences between the means, the data were analyzed using Duncan's multiple range test (DMRT) in the SPSS Statistics 17.0 software (IBM, Chicago, USA). A significant difference at $p \leq 0.05$ was shown by the different letters in superscript in the same column.

Table 2 Effect of the incorporation of oleogel on the color attributes of the developed cookies[a]

Sample	Weight loss (%)	Diameter (mm)	Thickness (mm)	Spread ratio	L	a	b
O_0	16.11 ± 0.92^d	47.97 ± 1.05^a	7.62 ± 0.35^b	6.30 ± 0.35^a	68.78 ± 3.78^b	5.66 ± 1.96^a	20.63 ± 0.85^a
O_{20}	14.53 ± 0.84^c	48.13 ± 0.92^a	7.23 ± 0.41^a	6.67 ± 0.37^{ab}	66.81 ± 4.04^b	6.71 ± 1.94^a	20.86 ± 0.59^a
O_{40}	12.94 ± 0.62^b	48.20 ± 0.72^a	7.18 ± 0.51^a	6.74 ± 0.53^b	68.78 ± 2.98^b	5.82 ± 1.43^a	20.17 ± 0.59^a
O_{60}	12.73 ± 0.8^b	48.42 ± 1.01^a	7.14 ± 0.56^a	6.81 ± 0.50^b	57.45 ± 4.79^a	10.36 ± 0.92^b	22.57 ± 1.45^b
O_{80}	11.83 ± 0.70^{ab}	48.51 ± 1.10^a	7.07 ± 0.22^a	6.85 ± 0.19^b	57.67 ± 4.49^a	10.25 ± 1.26^b	22.59 ± 0.96^b
O_{100}	11.38 ± 0.91^a	48.62 ± 0.70^a	6.95 ± 0.42^a	7.01 ± 0.40^b	56.71 ± 5.64^a	10.47 ± 1.49^b	22.6 ± 1.34^b

[a] Means with different superscripts in the same row indicate that there is a significant difference between samples ($p \leq 0.05$) from Duncan's multiple range tests.

3. Results and discussion

3.1. Physical properties of cookies

The physical properties of the cookies were analyzed in terms of weight loss, diameter, thickness and spread ratio, as summarized in Table 2. The weight-loss percentage of the cookies decreased with an increase in oleogel concentration. The cookie sample O_0 had the highest weight loss of 16.11% during baking, whereas the cookie sample O_{100} had the lowest weight loss at 11.38%. The weight loss of cookies during baking generally refers to the reduction in mass due to the evaporation of moisture and the release of gases. Oleogels are structured oils, and there is less moisture to evaporate during baking, which minimizes weight loss.[20] Additionally, oleogel networks were proposed as a way to prevent moisture migration during baking. In addition, the natural deep eutectic solvent inhibited moisture from evaporation during baking. Similar kind of observation was reported by Savi[21] with citric acid and sucrose NADES during baking. The diameter of cookies slightly increases with increasing oleogel concentration, whereas the thickness of the cookies shows a slight decrease. The observed result was similar to that of Kim and Oh.[22] Kim and Oh[22] compared cookies made with shortening and a Tenebrio Molitor larvae oil-based oleogel using oleogelators (candelilla wax, carnauba wax, and beeswax). They found that cookies made with beeswax oleogel had the highest diameter and the lowest thickness. Similar results were reported by Öğütcü, Arifoğlu, and Yılmaz[23] in studies with sunflower wax and beeswax/hazelnut oil-oleogelin cookies. The melted oleogel could result in more free oil within the dough during baking, which encourages spreading as the structure softens. This free oil reduces internal rigidity in the dough, enabling it to spread wider, thus increasing the cookie diameter and reducing thickness. It is obvious that as the diameter increases and the thickness reduces, the spreadability increases, as confirmed by our present findings. The present findings are in agreement with the previously conducted study.[22]

3.2. Color attributes of cookies

The color of 15 randomly selected samples was analyzed in terms of L, a, and b values (Table 2). The brightness of the cookie sample without oleogel (O_0) was found to be the highest. The results reveal that cookies with a higher concentration of oleogel were darker compared to those made with butter. The oleogel, composed of beeswax, starch, and NADES, markedly reduced the L value of the cookies. The sample O_{100} showed the highest a (redness) and b (yellowness) values. It was suggested that malic acid and glucose could participate in non-enzymatic browning reactions at high temperatures, contributing to the formation of brown pigments (melanoidins).[24] This result is consistent with that obtained by Li,[15] who investigated the effect of oleogels prepared with five different gellators (hydroxypropylmethylcellulose, mono-acylglycerol, sodium stearyl lactate, rice bran wax, and beeswax) on cookie attributes.

3.3. Textural properties of cookies

Texture analysis of the cookies revealed that fracturability and hardness of the cookies decreased significantly ($p < 0.05$) with increasing oleogel concentration (Table 3). This result could be due to the high fat content of the oleogel. The eutecto-oleogel exhibits low internal resistance to flow because its microstructure consists of a weak, partially crystalline network formed by beeswax and starch that entraps oil and NADES components.

Table 3 Textural and functional attributes of cookies[a]

Sample	Fracturability (N)	Hardness (N)	WAI (%)	WSI (%)
O_0	47.45 ± 2.06^d	80.75 ± 2.64^e	183.35 ± 1.008^e	31.13 ± 1.02^a
O_{20}	45.93 ± 1.40^{cd}	76.66 ± 2.67^d	167.97 ± 3.56^d	31.06 ± 0.54^a
O_{40}	43.85 ± 1.36^{bcd}	71.46 ± 2.20^c	152.32 ± 3.33^c	29.83 ± 0.59^a
O_{60}	42.93 ± 3.97^{bc}	67.47 ± 2.54^b	150.08 ± 0.95^b	30.90 ± 0.44^a
O_{80}	40.52 ± 3.36^b	64.15 ± 1.49^a	149.91 ± 1.64^b	31.48 ± 1.51^a
O_{100}	36.01 ± 2.88^a	62.66 ± 2.64^a	142.06 ± 0.70^a	31.15 ± 1.02^a

[a] Means with different superscripts in the same row indicate that there is a significant difference between samples ($p \leq 0.05$) from Duncan's multiple range tests.

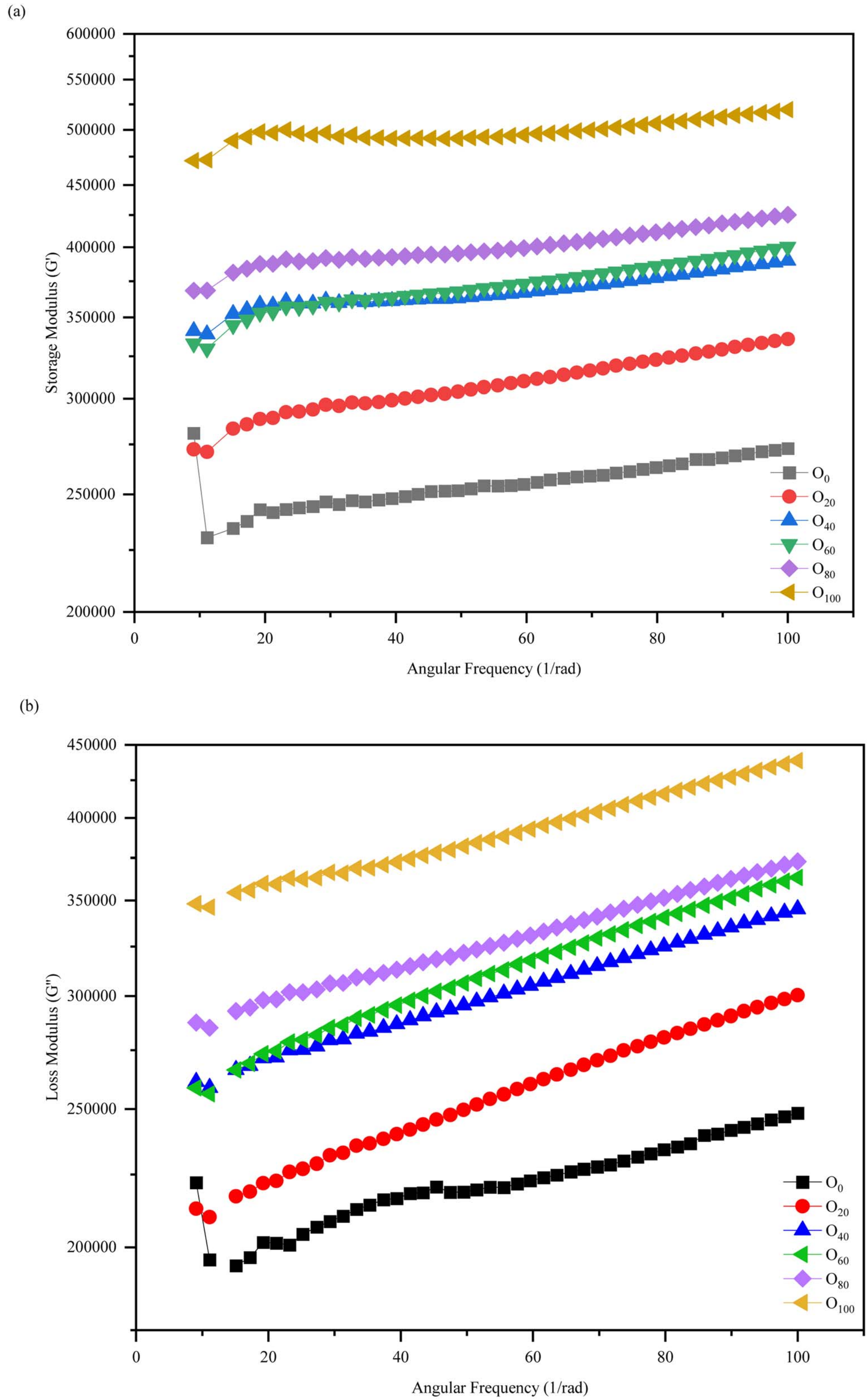

Fig. 1 Rheological behaviour of dough samples: (a) storage modulus and (b) loss modulus.

Oils possess a loosely packed molecular structure with weak intermolecular interactions, which results in low internal resistance to flow. This structural arrangement allows oil molecules to move and slide past one another with minimal energy input. When applied between solid surfaces, the mobile oil molecules spread uniformly and form a continuous, thin lubricating layer. This layer separates the surfaces and prevents direct solid–solid contact, thereby reducing friction and stress concentration. Consequently, less force is required to initiate crack formation and propagation, leading to lower fracture energy. Similarly, reduced resistance to surface deformation manifests as lower measured hardness. A similar result has been found by Jadhav *et al.*[25] for cookies containing oleogel. Cookies with medium-chain triglyceride oleogel showed lower hardness compared to butter cookies.[25] A similar observation was reported by Emin Yılmaz and Mustafa Öğütcü[11] when cookies made by incorporating commercial bakery shortening and a beeswax-based oleogel were investigated.

3.4. Functional properties of cookies

Water absorption index (WAI) and water solubility index (WSI) were evaluated to determine the functional properties of the cookies (Table 3). The water absorption index was found to decrease with increasing oleogel concentration from 183.35% to 142.06%. The oleogel contains a high amount of rice bran oil; thus, the cookies showed hydrophobic properties.[24] When an eutecto-oleogel is incorporated into the cookie dough, its structured oil and NADES network surrounds part of the water present in the system. This reduces the amount of free water available to interact with hydrophilic components such as starch and proteins. Since these components rely on direct contact with water to swell, hydrate, and bind moisture, the presence of oleogel decreases their ability to absorb water effectively. As a result, the overall water absorption capacity of the dough decreases. This limited water availability can influence dough handling, texture, and spread during baking, as less water is taken up by the flour components. A similar observation was reported by Oh and Lee[26] for noodles with the soybean oil-candelilla wax oleogel. The water solubility index of the cookies was not affected significantly in the presence of oleogels. Oleogels do not affect the water solubility of cookies because they are hydrophobic and interact with the fat phase rather than the water phase. Mert and Demirkesen[27] reported similar observations for cookies with candelilla wax-containing oleogels.

3.5. Rheological properties of dough

Rheological analysis was conducted to investigate the effect of the incorporation of oleogel on the flow properties of dough developed for cookies. Fig. 1(a) and (b) present the storage modulus (G′) and loss modulus (G″) of the samples. The storage modulus of the dough sample shows an increasing trend with an increase in oleogel concentration. This result indicates that the rigidity of the dough increased with an increase in oleogel concentration. The oleogel provides additional reinforcement to the dough's internal network, leading to increased resistance to deformation. The dough becomes more elastic and able to recover its shape after stress is applied, hence a higher G′ was observed. On the other hand, increasing the concentrations of starch and beeswax within the eutecto-oleogel system enhances the overall structural firmness because both components contribute to a more solid, interconnected network. Beeswax forms crystalline structures that remain solid at room temperature, acting as a rigid scaffold. Starch granules, when present in higher amounts, add additional bulk and structural support. Together, they limit molecular mobility within the matrix, making the eutecto-oleogel more stable and less deformable. This strengthened network increases rigidity, resulting in a firmer texture and a more robust structure that better resists mechanical stress or deformation during handling or processing. Loss modulus also shows a similar trend to the storage modulus for dough.

3.6. Proximate composition of cookies

The moisture content of the cookies increased with increasing oleogel concentration in the sample (Table 4). The present results on weight loss during baking justify the observed

Table 4 Proximate composition of cookies[a]

Sample	Moisture (%)	Ash (%)	Fat (%)	Protein (%)
O_0	2.45 ± 0.16[a]	1.01 ± 0.07[d]	13.88 ± 0.20[a]	6.25 ± 0.12[a]
O_{20}	2.95 ± 0.29[b]	0.94 ± 0.05[d]	14.46 ± 0.01[b]	6.25 ± 0.25[a]
O_{40}	3.12 ± 0.18[b]	0.84 ± 0.01[c]	14.99 ± 0.01[c]	6.25 ± 0.10[a]
O_{60}	3.44 ± 0.13[c]	0.74 ± 0.02[bc]	15.59 ± 0.12[d]	6.24 ± 0.02[a]
O_{80}	3.62 ± 0.04 [cd]	0.66 ± 0.08 [ab]	16.24 ± 0.13[e]	6.24 ± 0.14[a]
O_{100}	3.86 ± 0.10[d]	0.59 ± 0.01[a]	16.79 ± 0.14[f]	6.24 ± 0.01[a]

[a] Means with different superscripts in the same row indicate that there is a significant difference between samples ($p \leq 0.05$) from Duncan's multiple range tests.

Table 5 Sensory attributes of the developed cookies[a]

		Texture				
Sample	Color	Fracturability	Bite hardness	Taste	Flavour	Overall acceptability
O_0	7.06 ± 0.96[a]	7.46 ± 0.91[a]	7.33 ± 0.72[a]	7.86 ± 0.74 [ab]	7.66 ± 0.61[b]	7.47 ± 0.83[bc]
O_{20}	7.46 ± 1.06[a]	7.53 ± 1.06[a]	7.53 ± 1.24[a]	7.73 ± 0.70 [ab]	7.6 ± 0.82 [ab]	7.67 ± 0.89[bc]
O_{40}	7.46 ± 0.83[a]	7.53 ± 0.99[a]	7.33 ± 0.97[a]	7.40 ± 0.91 [ab]	7.33 ± 0.97 [ab]	7.33 ± 0.97[abc]
O_{60}	7.53 ± 0.83[a]	7.40 ± 1.12[a]	7.13 ± 1.12[a]	8.06 ± 0.96[b]	7.73 ± 0.79[b]	7.73 ± 1.03[c]
O_{80}	7.06 ± 1.22[a]	6.86 ± 0.99[a]	6.86 ± 1.12[a]	7.26 ± 0.96[a]	6.93 ± 0.79[a]	6.93 ± 0.79 [ab]
O_{100}	6.73 ± 1.03[a]	6.73 ± 1.03[a]	6.73 ± 1.38[a]	7.13 ± 1.12[a]	7.07 ± 1.16 [ab]	6.67 ± 1.17[a]

[a] Means with different superscripts in the same row indicate that there is a significant difference between samples ($p \leq 0.05$) from Duncan's multiple range tests.

moisture content of the cookies. Cookies with a higher concentration of oleogel lose less moisture during baking. Oleogels are structured oil systems in which the liquid oil is entrapped in a three-dimensional network formed by starch, beeswax, and NADES. This structure could influence the interaction of water with cookies and the evaporation of water during baking. The fat percentage also showed an increasing trend with the increase in oleogel concentration in the cookies. Oleogels are typically structured oils, where liquid oil is trapped within a gel matrix, while butter contains both fat and water. Butter usually contains around 80% fat, about 15–20% water, and other milk solids. On the other hand, oleogels consist almost entirely of fat. Thereby, this difference in composition means that when the same quantity of oleogel and butter is used in a recipe, the oleogel inherently provides more fat content because it lacks the water and solids present in butter. A similar result has been reported by Yilmaz *et al.*[28] who investigated cookies made using hazelnut oil-based oleogel structured using sunflower wax/beeswax and commercial bakery shortening. It was reported that the fat percentage of the cookies with beeswax-based oleogel was highest. The ash content of the cookie sample decreases with an increase in the oleogel content. Similar observations have been made by Yilmaz *et al.*.[28] The protein content of various samples does not show a significant difference (Table 5).

3.7. Sensory analysis

The sensory evaluation of various cookie samples was performed according to a 9-point hedonic scale to determine consumer acceptance (Table 5). The sample with varying amount of oleogel showed comparable sensory properties of cookies with control O_0 sample. The overall acceptability of the cookies sample O_{60} was found to be the highest (7.73), followed by O_{20} and O_0. The color, taste and flavour of the O_{60} cookie sample comparatively showed the highest acceptance by the panel among all the samples. In the presence of oleogel, cookies create a smooth and creamy mouthfeel that enhances the perception of richness, which is often a desirable sensory trait. As oleogels are made from liquid oils, the release of flavors tends to be more efficient, which improves the overall sensory experience of cookies.

3.8. Shelf life of cookies

For self-life analysis, the cookie sample O_{60} was selected, as it showed the highest favourable sensory attribute. A short-term (35 days) storage study was carried out at two different relative humidity levels of 75% and 94%. Every 7th day, the textural attributes, *i.e.*, fracturability and hardness, moisture content and peroxide values, of O_{60} were measured and compared with the control sample O_0.

3.8.1. Moisture content. The moisture content of all cookie samples was analyzed at intervals of 7 days till 35 days. The moisture content of the oleogel sample was found to be higher than that of the O_0 sample under both relative humidity conditions. Fig. 2(a) shows the increase in moisture with storage days. The moisture content of the cookie sample

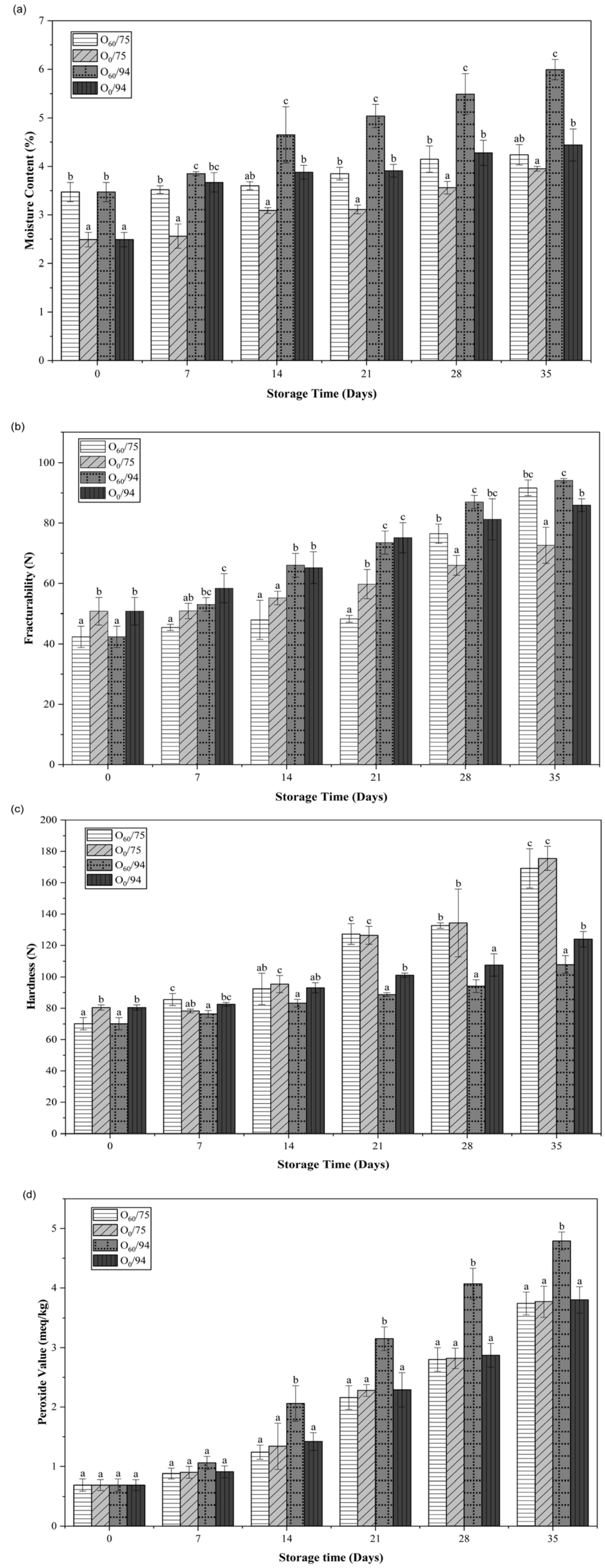

Fig. 2 Effect of storage on (a) moisture content, (b) fracturability, (c) hardness and (d) peroxide values of the cookies samples during storage (O_{60}/75: sample containing 60% oleogel and stored at 75% RH; O_0/75: sample containing 100% butter and stored at 75% RH; O_{60}/94: sample containing 60% oleogel and stored at 94% RH; and O_0/94: sample containing 100% butter and stored at 94% RH).

increased gradually at 75% RH, whereas the samples stored at 94% RH picked up moisture very rapidly in comparison. The O_{60} sample stored at 94% RH was found to have the highest moisture content at the end of 35 days. It was suggested that due to the presence of oleogels in the cookies, the porosity in the network increases, which allows more space in the structure and thus a higher amount of moisture penetrates into the cookie.

3.8.2. Fracturability and hardness. Fracturability and hardness of the entire cookie sample show increasing trend with increasing days of storage. Moisture changes, starch retrogradation, fat crystallization, and other structural changes are the main causes of increased fracturability and hardness of cookies during storage.[29] The control sample O_0 stored at 75% RH showed the least fracturability at the end of 35 days, whereas the O_{60} sample stored at 94% RH showed the highest fracturability. The cookies with butter might exhibit a lower rate of moisture loss as well as starch retrogradation as compared to cookies with oleogel.

3.8.3. Peroxide value. The peroxide value of the cookies was measured to estimate the oxidative stability of the products. Results revealed that the O_0 cookies have similar peroxide values at both the storage conditions of 75% RH and 94% RH. However, the O_{60} sample showed that the storage condition elevated the peroxide value of the cookies made using oleogel. At the storage condition of 75% RH, the O_{60} sample showed a peroxide value similar to that of butter cookies, but at 94% RH, the peroxide value increased drastically. Oleogels are made from rice bran oils that are rich in unsaturated fatty acids, particularly polyunsaturated and monounsaturated fats. These unsaturated fats are more prone to oxidation compared to the saturated fats present in butter, thus cookies with oleogels showed higher peroxide values during storage.

4. Conclusion

The study successfully demonstrated that oleogel could replace the solid fat in the confectionery. Rice bran oil was used as a solid fat replacer, an oleogel was successfully prepared using rice bran oil and natural wax, and oleogelation effectively improved oxidative stability during storage under accelerated conditions. As a result of applying the oleogel to cookies instead of shortening, the hardness of oleogel cookies with beeswax was lower than that of shortening cookies and tended to become softer. In addition, the oleogel cookie with beeswax did not show significant differences in spread factor and texture properties compared to the cookie with shortening, indicating the possibility of serving as an alternative to shortening.

The study demonstrated that eutecto-oleogel is a promising fat replacer in cookies, as formulations up to 60% oleogel delivered desirable physicochemical, textural, and sensory qualities. Oleogel cookies closely matched control samples and maintained stability during storage, indicating their potential for developing healthier bakery products without compromising quality.

Author contributions

Deepali Deepali: methodology, formal analysis, data curation. Poonam Mishra: conceptualization, resources, review & editing the final draft, supervision, funding acquisition. Amit Baran Das: resources, review & editing the final draft, supervision, funding acquisition.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All the data are incorporated in the manuscript.

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